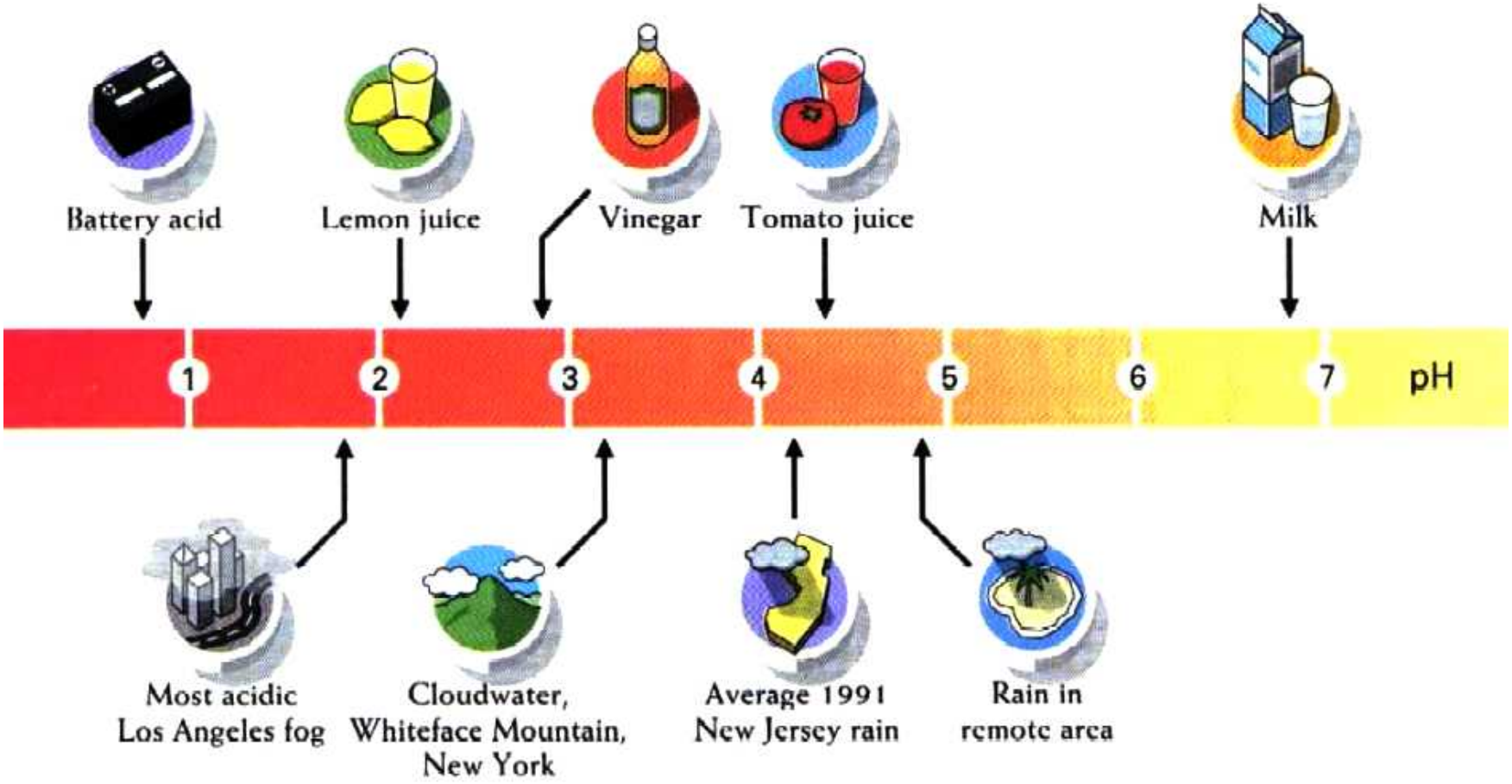
Acid Deposition

1. What is Acid Deposition (or Acid Rain)?
2. What factors may influence acid deposition?
3. What Are the Impacts of Acid Deposition?
    - One cause of forest dieback.
    - Loss of base cations (Ca^{2+}, Mg^{2+}) and other soil nutrients
    - Acidifying lakes and other ecosystems
4. Trend of Acid Deposition in the US
5. Policies for Reducing Acid Deposition

What is acid deposition or acid rain?

Acid rain or acid deposition is caused by sulfur compounds and NO_x in the atmosphere (The final forms are: SO_2, SO_3, and NO_2. They become acids when react with rain water in the air).

Although NO_x is definitely involved in forming acid rain, sulfur has long been identified as the most important element contributing to the acid rain problem because virtually all sulfur emissions to the atmosphere are oxidized into either SO_2 or SO_3 which become acids when dissolved in rain water.

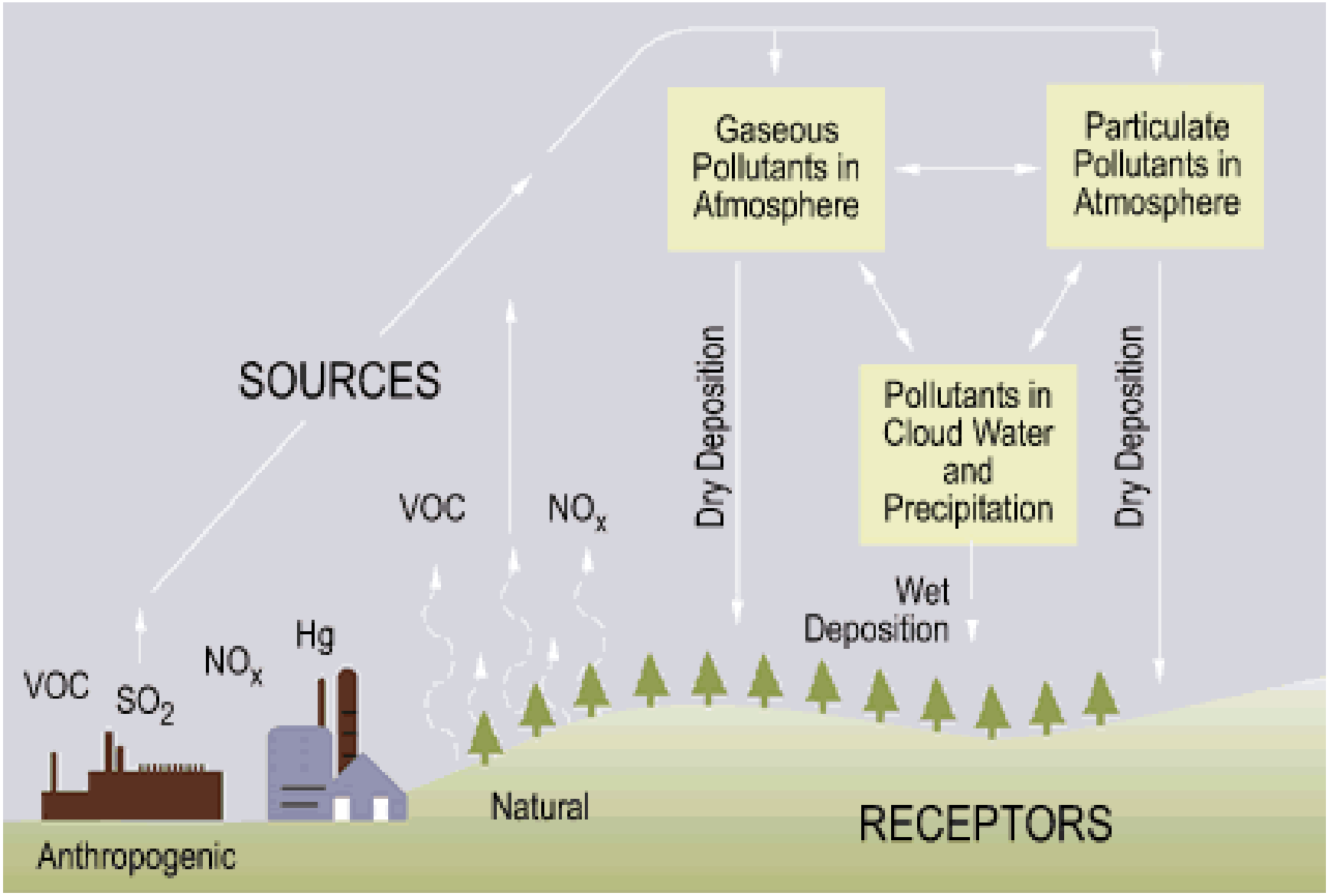


The pH values in atmospheric water of various types, compared with the pH values for several common liquids.

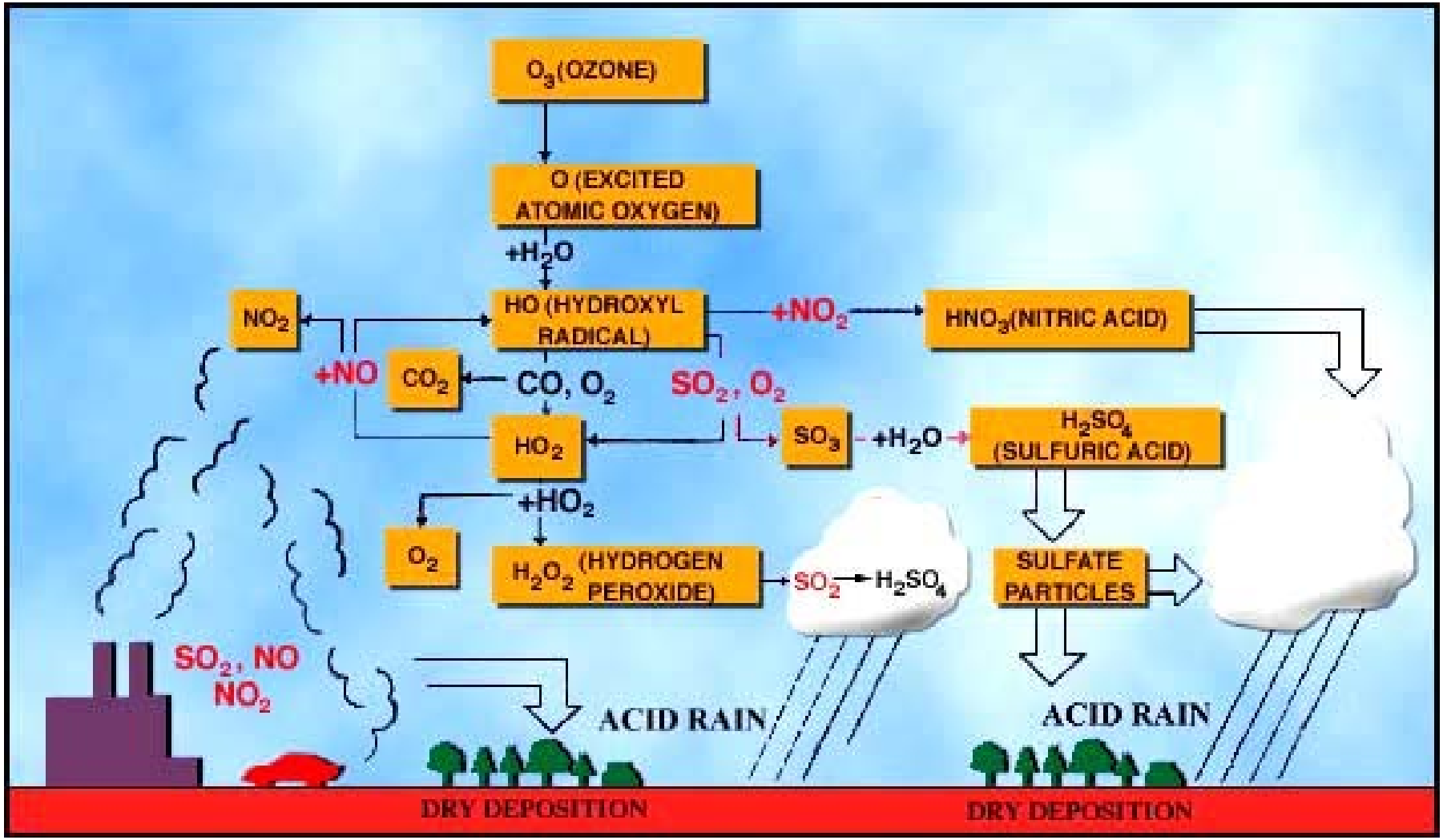
Chemistry of Acid Rain

$SO_2 + OH^- \rightarrow HSO_3 \rightarrow SO_4^{2-} + 2H^+$

$+ \ H_2O_2 \rightarrow H_2SO_4 \ \ (SO_4^{2-} + 2H^+)$


Gaseous Pollutants in Atmosphere
Particulate Pollutants in Atmosphere
SOURCES
Dry Deposition
Pollutants in Cloud Water and Precipitation
Dry Deposition
VOC
NO_x
Wet Deposition
Hg
VOC
SO_2
NO_x
Natural
RECEPTORS
Anthropogenic

Source: EPA



Source: UMichigan

Chemistry of Acid Rain (Al)

$H^+ + \underset{\text{(gibbsite)}}{Al(OH)_3} \rightarrow H_2O + Al(OH)_2^+$

$Al(OH)_2^+ + H^+ \rightarrow H_2O + Al(OH)^{2+}$

$Al(OH)^{2+} + H^+ \rightarrow H_2O + Al^{3+}$

What other factors may influence acid deposition in addition to sulfate and nitrate?

A. Particulates in the air (containing alkaline cations such as Ca^{2+}, Mg^{2+}, etc.) may be able to neutralize acids in the rain.

B. Climate (wind, rain, snow etc.) and the residence time of any acid-forming gases are the main determinants of the distance of transport from the sources of emissions to the actual location of deposition.

Tellus (1983), *35B*, 77–80

SHORT CONTRIBUTION

Acid rain in an Amazon rainforest

Rain pH = 4.7

By BRUCE HAINES, *Department of Botany*, CARL JORDAN, HOWARD CLARK and KATHLEEN E. CLARK, *Institute of Ecology, University of Georgia, Athens, Georgia 30602 U.S.A.*

(Manuscript received November 16, 1981; in final form March 25, 1982)

ABSTRACT

Acid rain is reported from the Amazon territory of Venezuela. The volume weighted average pH was 4.7 for 70 storms sampled from January 1979 through February 1980. At this location, remote from point sources of industrial pollution, acid rain might result from natural biogeochemical processes in the rainforest, from global atmospheric pollution, or from some combination of natural and pollution processes.

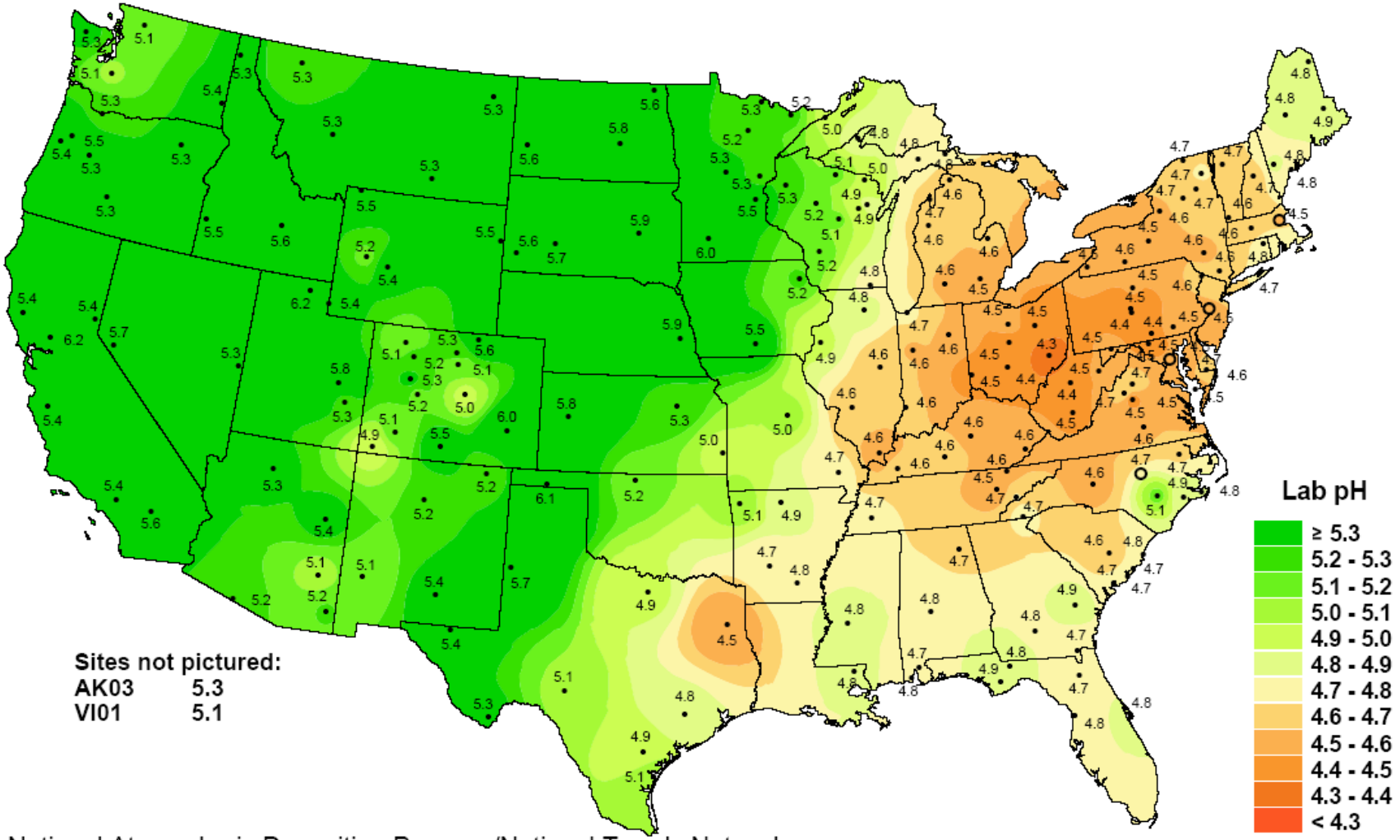
Forest ecosystem SO_4–S input-output discrepancies and acid rain: are they related?

Bruce Haines

Haines, B. 1983. Forest ecosystem SO_4–S input-output discrepancies and acid rain: are they related? – Oikos 41: 139–143.

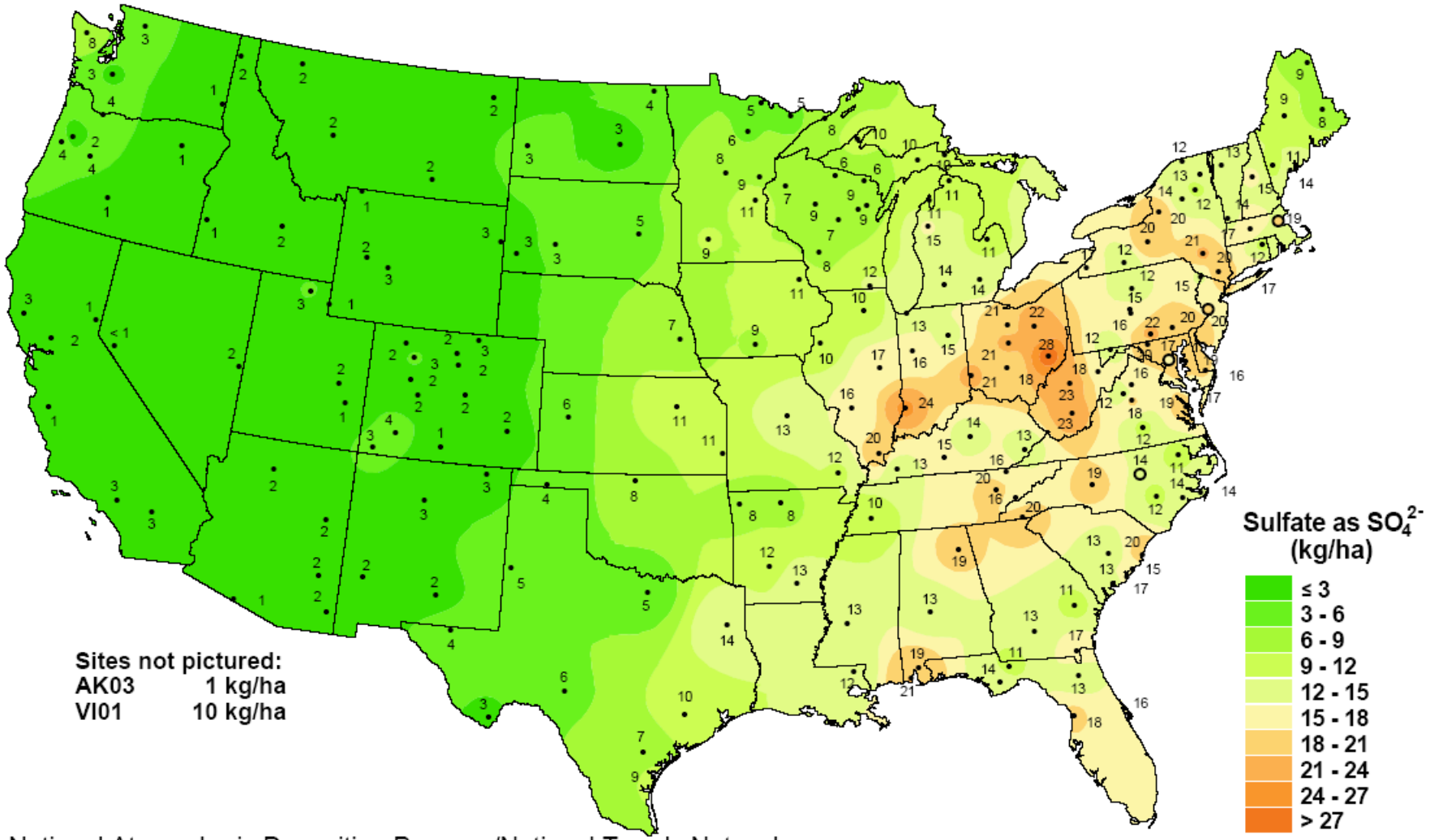
The SO_4–S inputs exceed SO_4–S outputs in rain forests at San Carlos de Rio Negro, Amazonas, Venezuela and at La Selva, Costa Rica. Hypotheses to explain excess of inputs over outputs include 1) accumulation of S in biomass, 2) accumulation of S in soil, 3) conversion of SO_4–S to organic S compounds which leave the system in drainage water, 4) conversion of SO_4–S to volatile S compounds which leave as gases, and 5) estimation errors. Acid rain occurs at both sites. If the S were volatilized out of the forest, oxidized in the atmosphere to SO_4, (4 above) then washed out of the atmosphere by rain, the resulting quantity of H_2SO_4 would be sufficient to account for the rainfall acidity observed in the field in Costa Rica.

Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory, 2005



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Sulfate ion wet deposition, 2005



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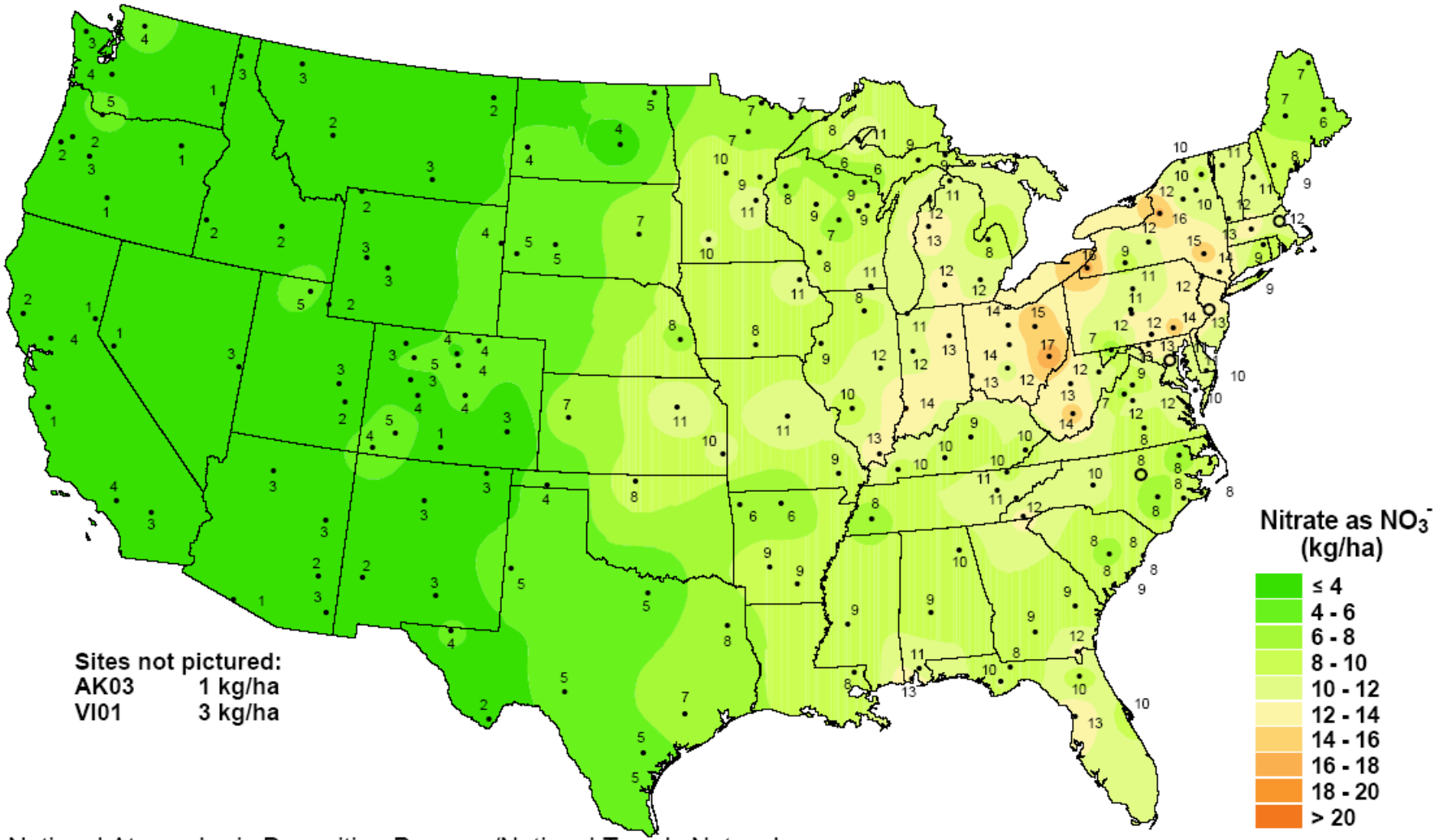
Nitrate ion wet deposition, 2005



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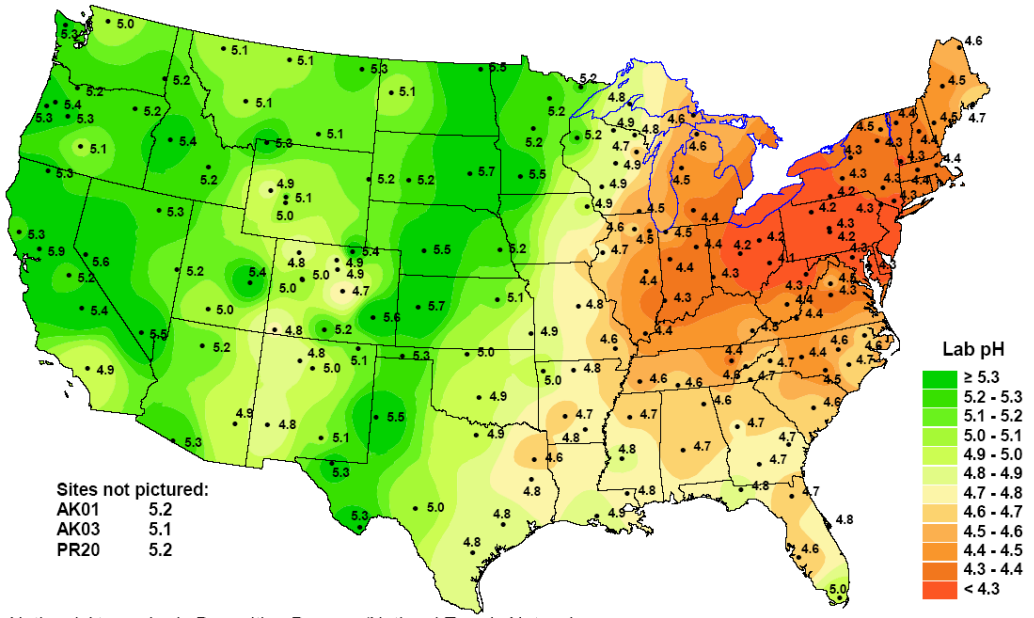
Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory, 1994



National Atmospheric Deposition Program/National Trends Network
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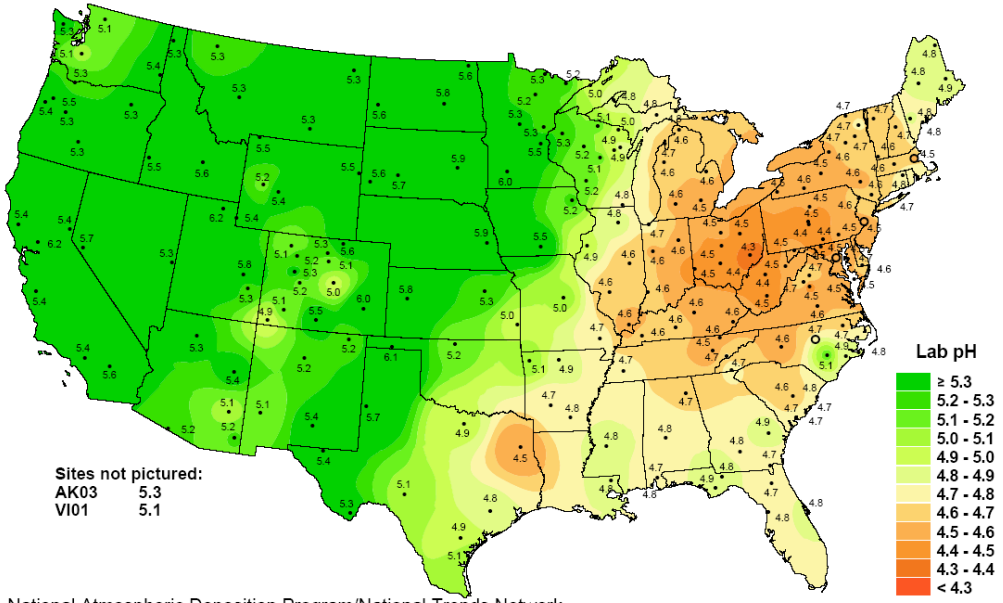
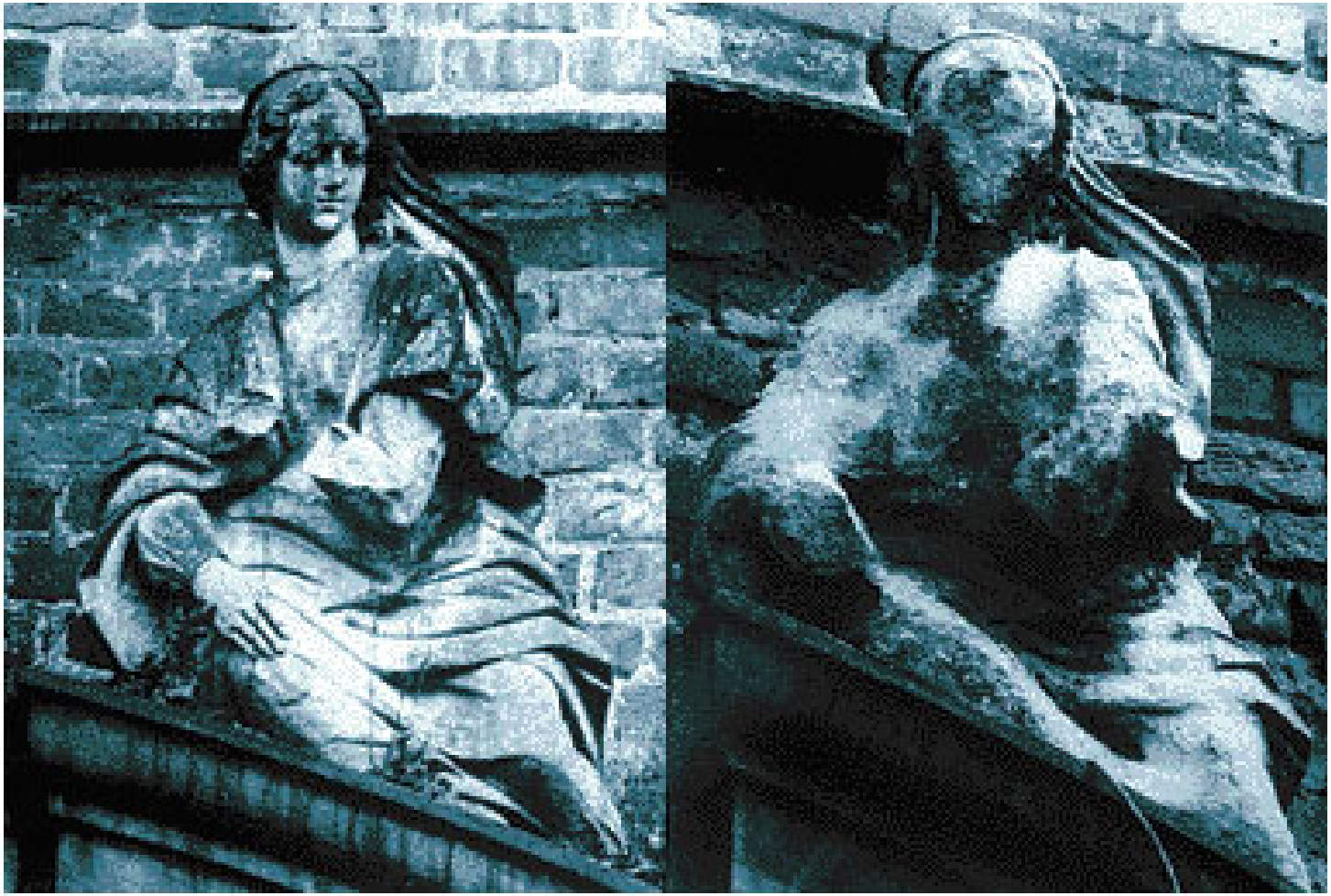
Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory, 2005



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

What Are the Impacts of Acid Deposition?

One cause of forest dieback.
Loss of base cations (Ca^{2+}, Mg^{2+}) and other soil nutrients
Acidifying lakes and other ecosystems

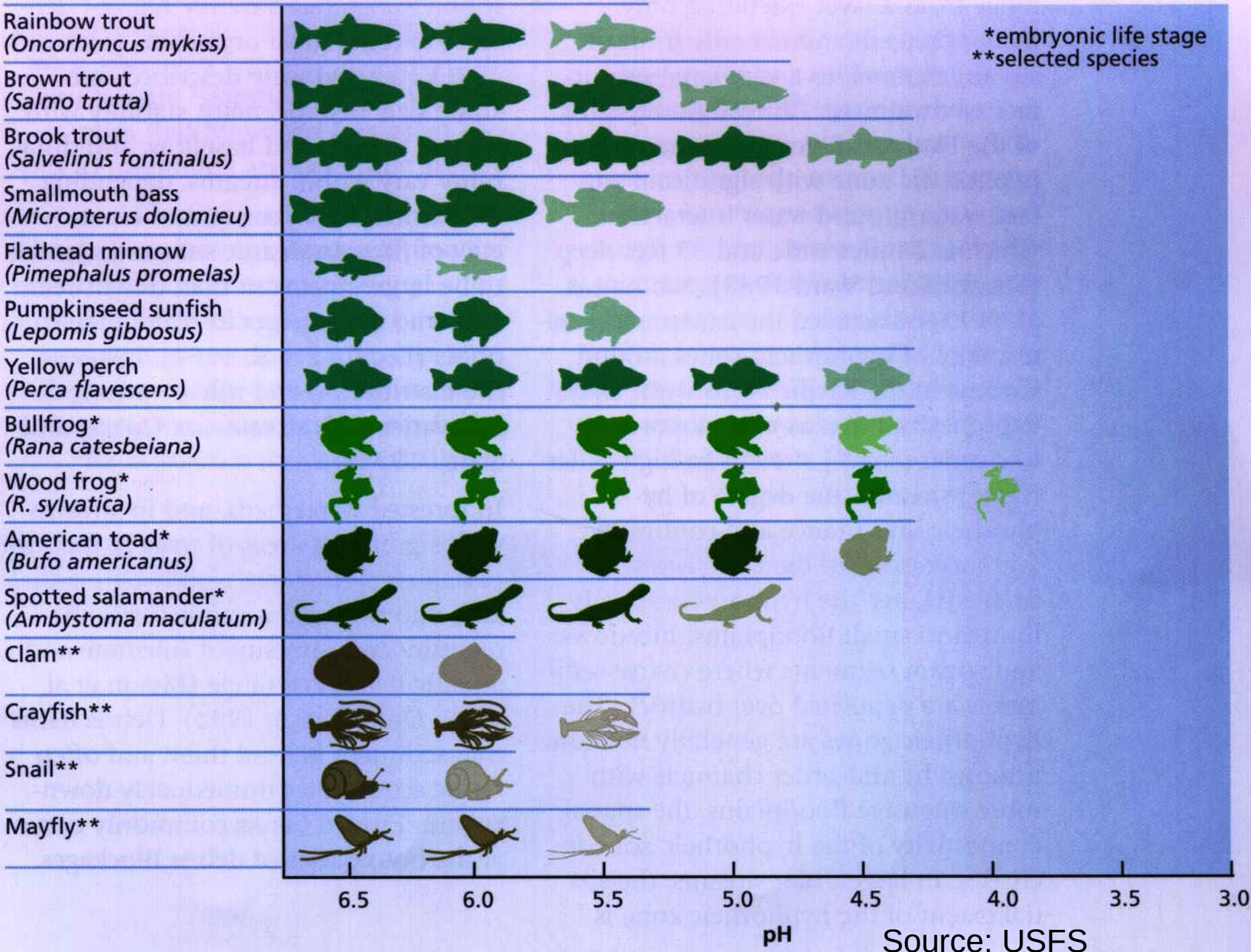


How acid rain affects stonework.
The picture on the left was taken in 1908.
The picture on the right was taken in 1968

Source: Westfäliches Amt fur Denkmalpflege

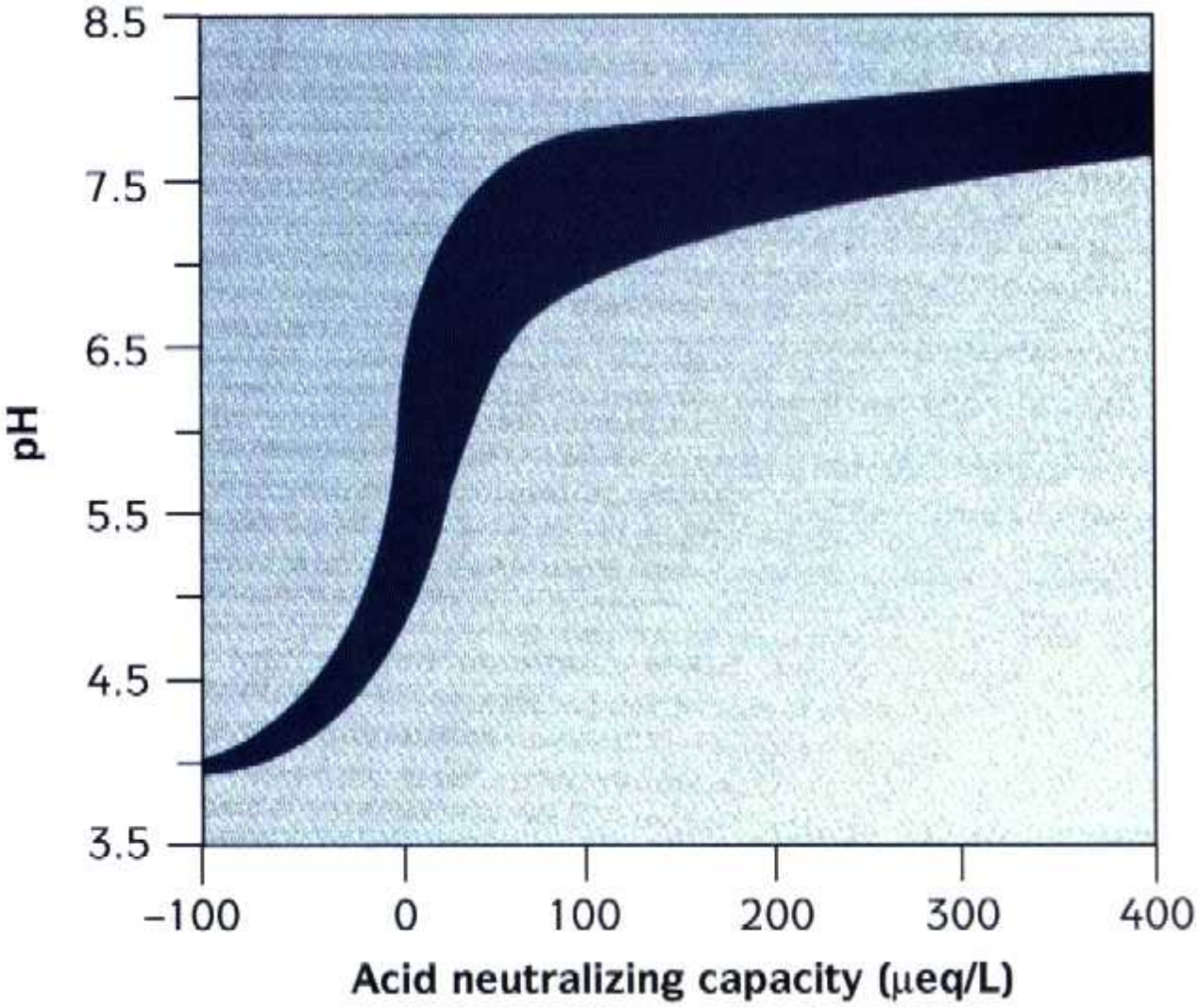
Source: David Smith, Doane College

The above photograph is a view of dying conifers in Germany. (Smil 1997, page 162). Acid rain has been the number one suspect.

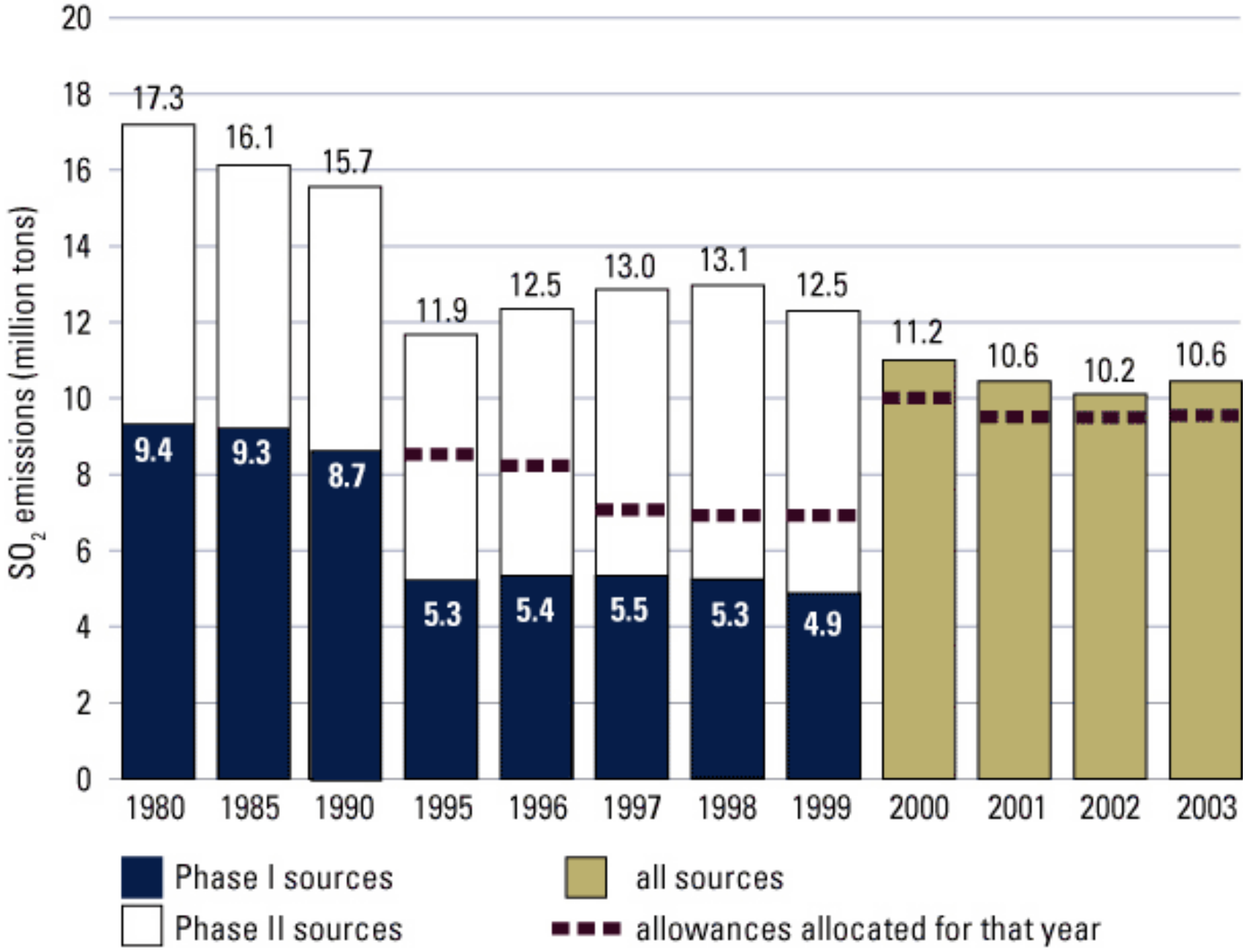

Rainbow trout
(Oncorhyncus mykiss)
Brown trout
(Salmo trutta)
Brook trout
(Salvelinus fontinalus)
Smallmouth bass
(Micropterus dolomieu)
Flathead minnow
(Pimephalus promelas)
Pumpkinseed sunfish
(Lepomis gibbosus)
Yellow perch
(Perca flavescens)
Bullfrog*
(Rana catesbeiana)
Wood frog*
(R. sylvatica)
American toad*
(Bufo americanus)
Spotted salamander*
(Ambystoma maculatum)
Clam**
Crayfish**
Snail**
Mayfly**
*embryonic life stage
**selected species
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
pH

Source: USFS

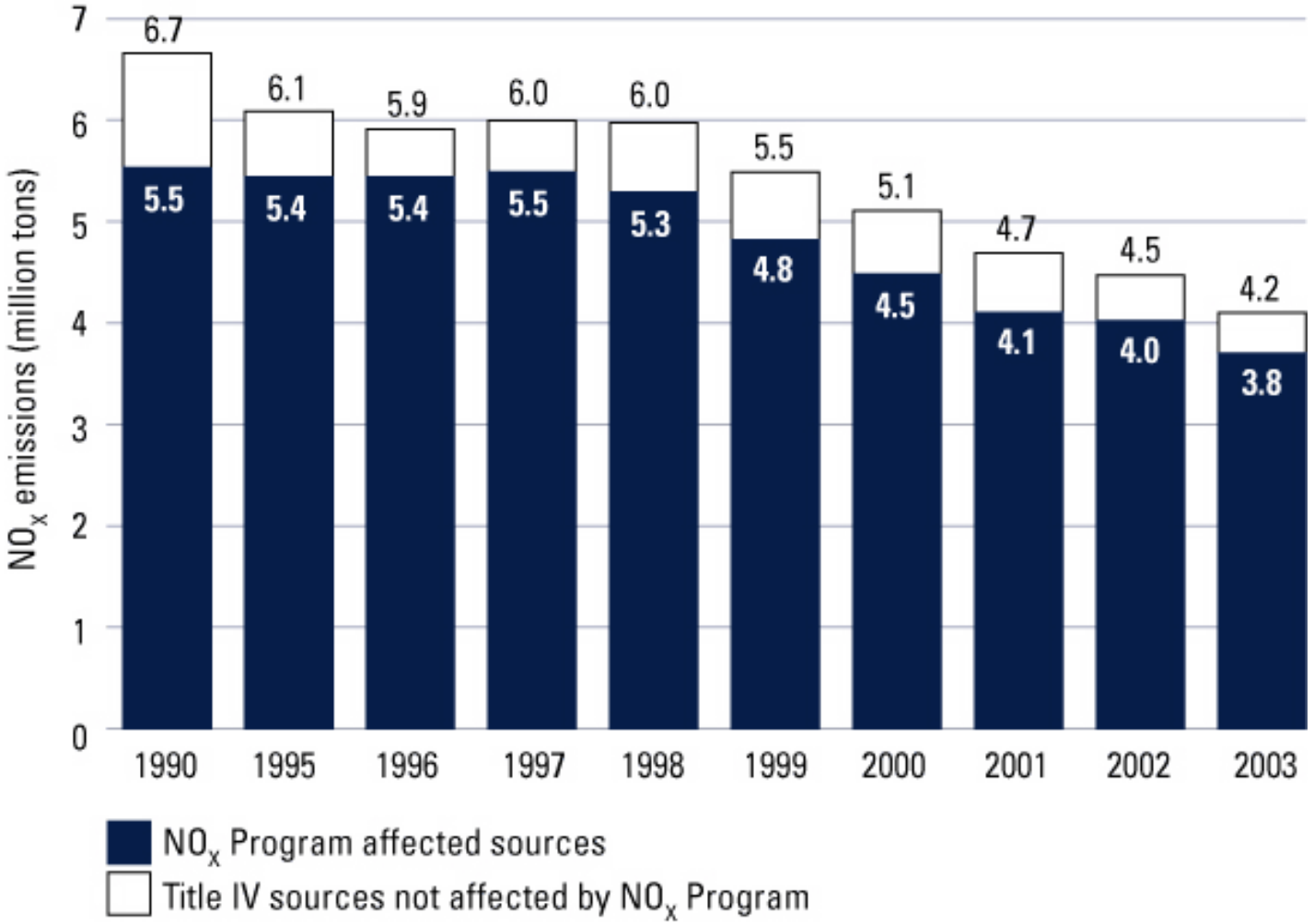
Acid rain may acidify lakes and other ecosystems, which can cause big changes of biological communities if the amount of acid deposition overpass the lake's neutralizing capacity.



Trend of Acid Deposition in the US

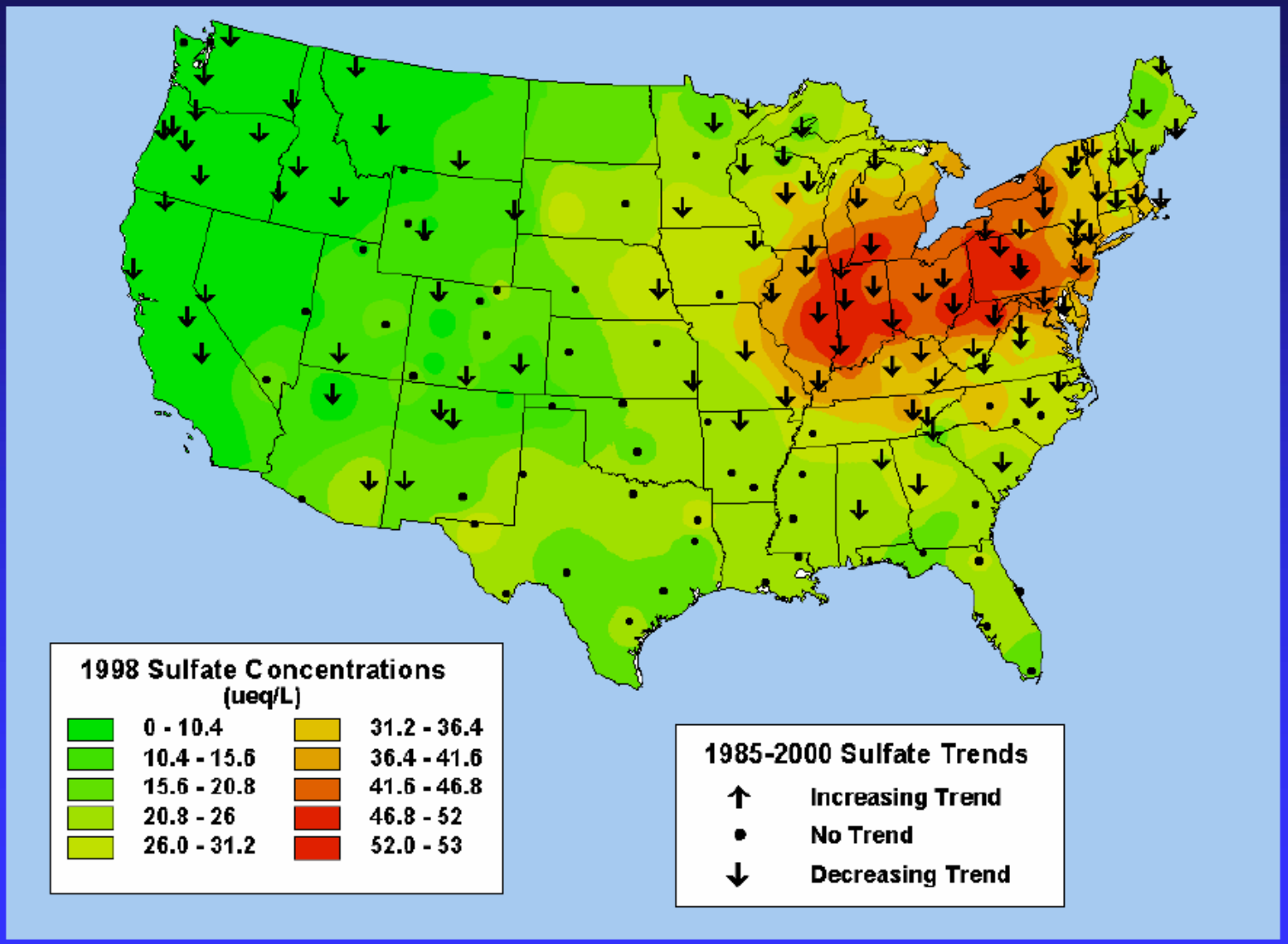


Source: US EPA



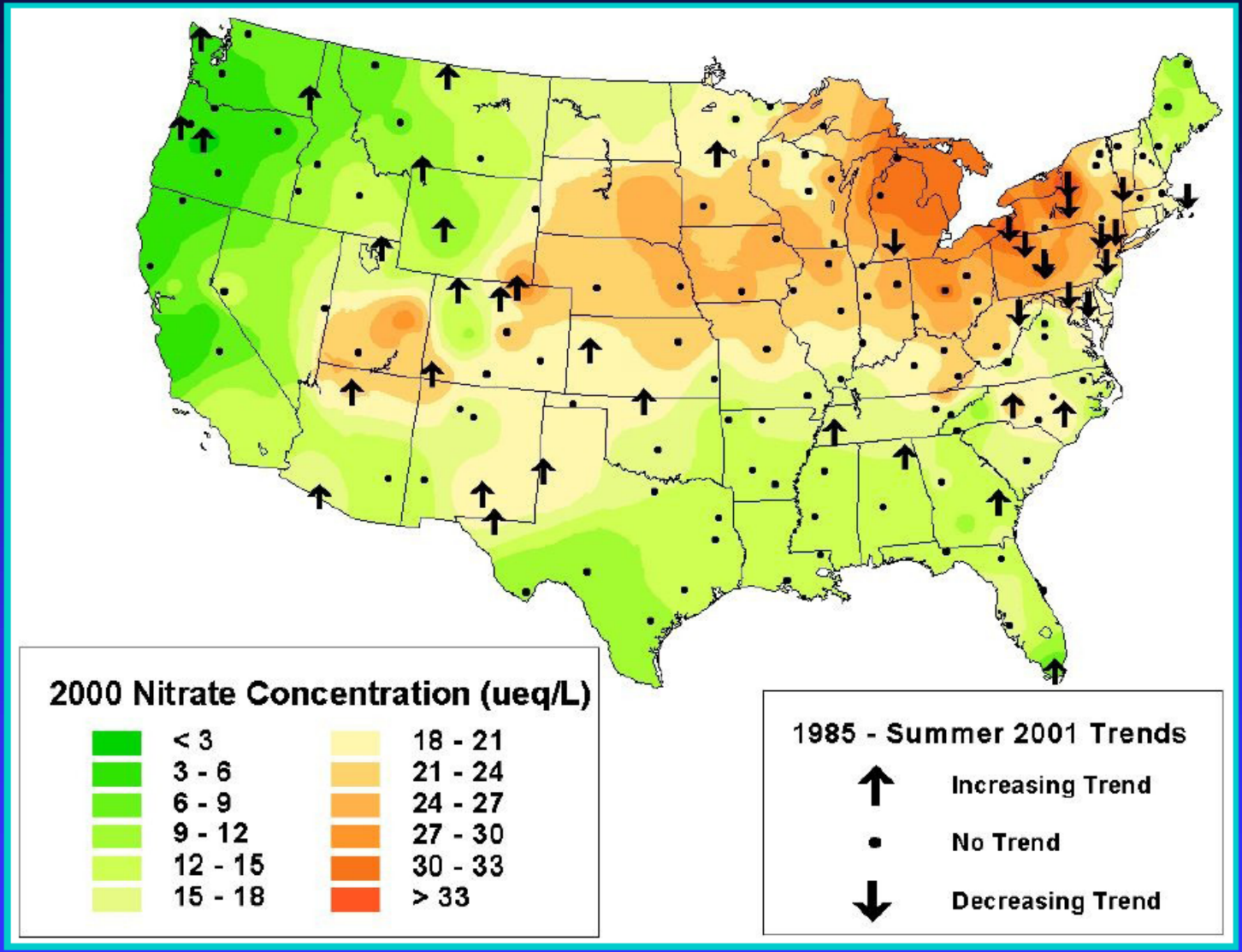
Source: US EPA

Trends in Sulfate in Precipitation 1985-2000



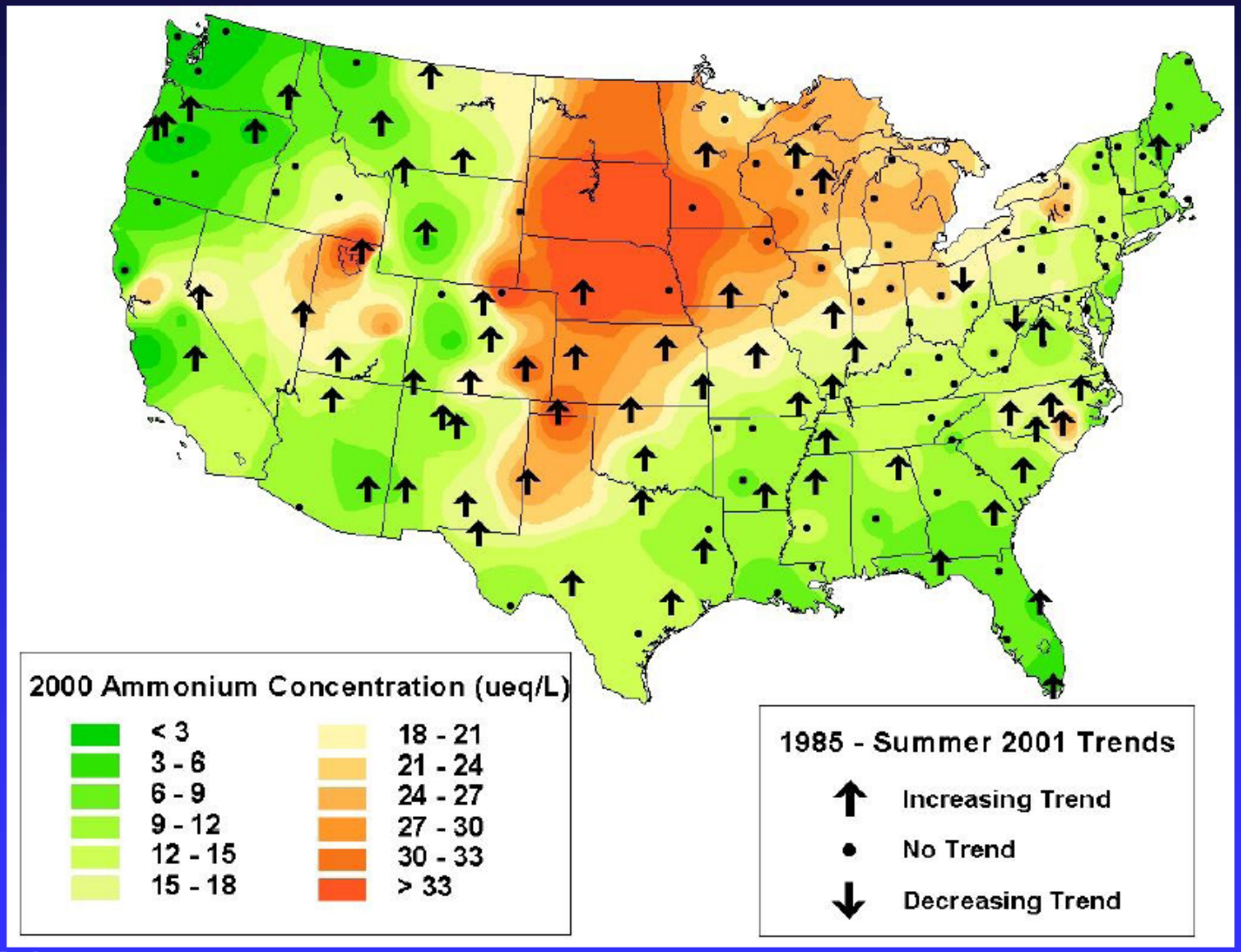
USGS

Nitrate Trends in Precipitation, 1985-2001



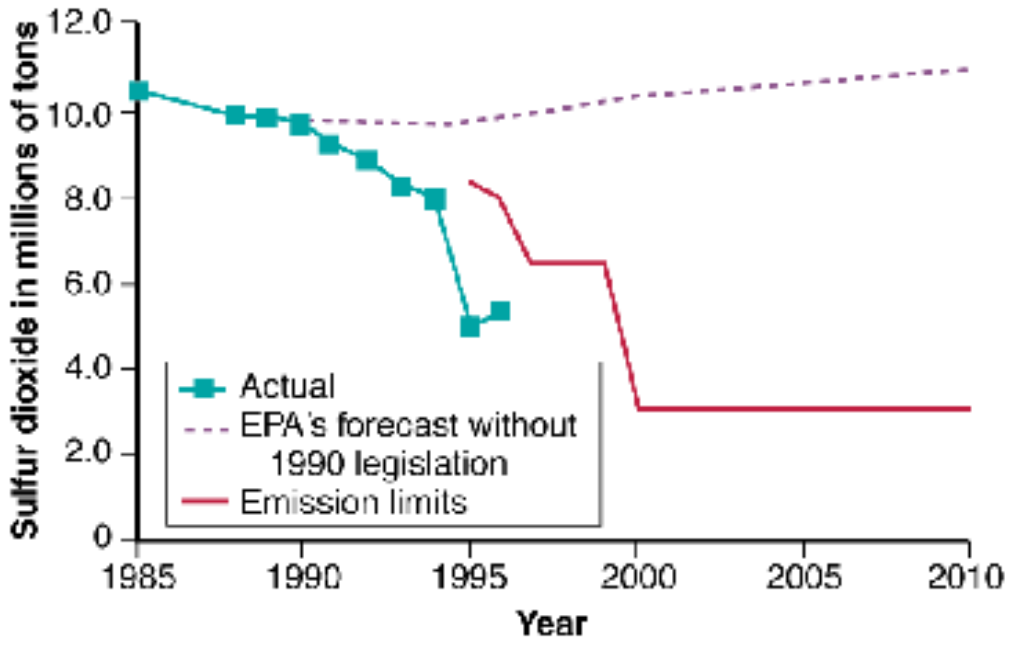
USGS

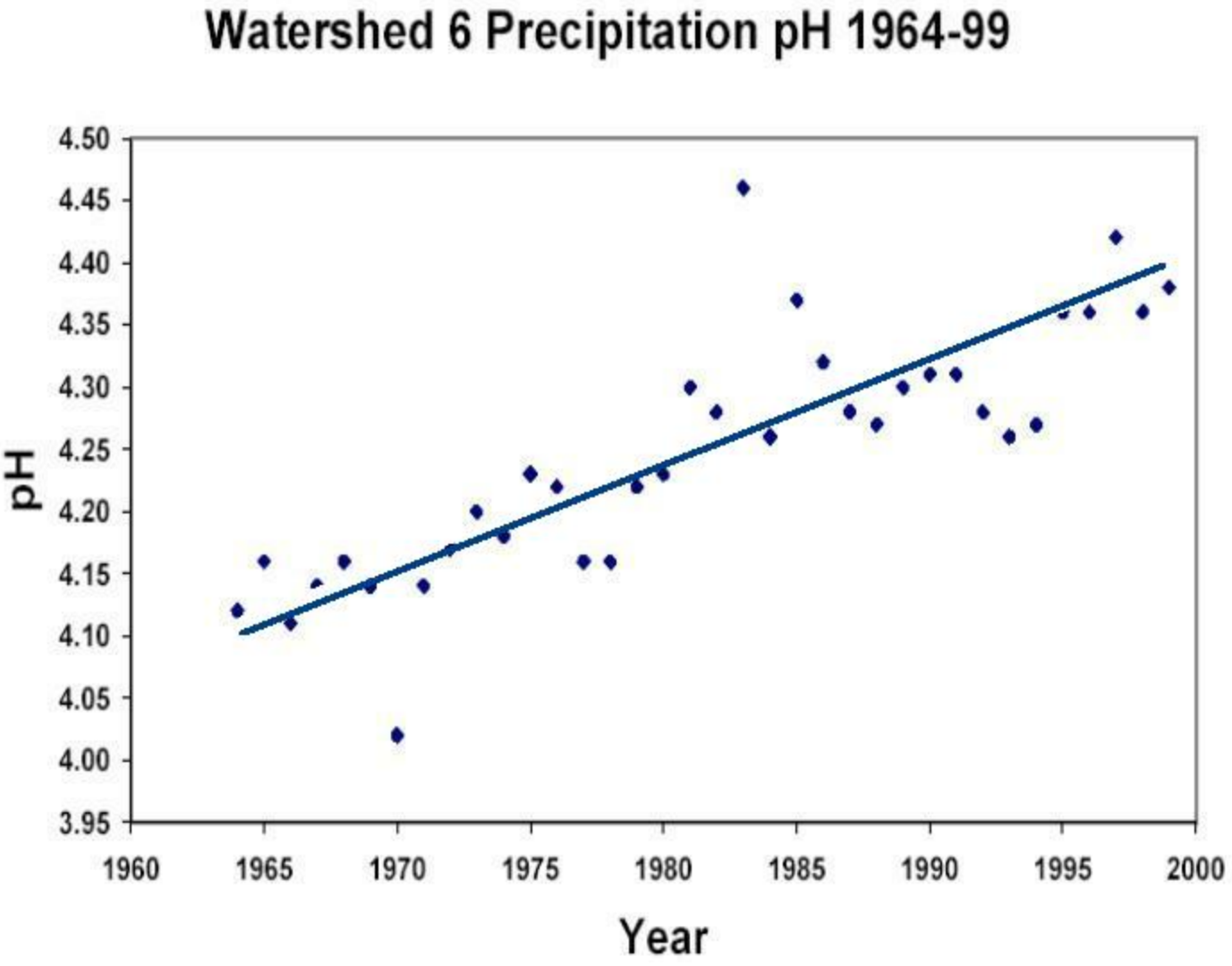
Trends in Ammonium Concentration 1985-2001



USGS

Acid Rain Control: Success on the Cheap (by Richard A. Kerr). In the United States, a flexible, free-market approach has helped to reduce SO_2 emissions at a bargain price. (Science, 1998. Vol 282: 1024)

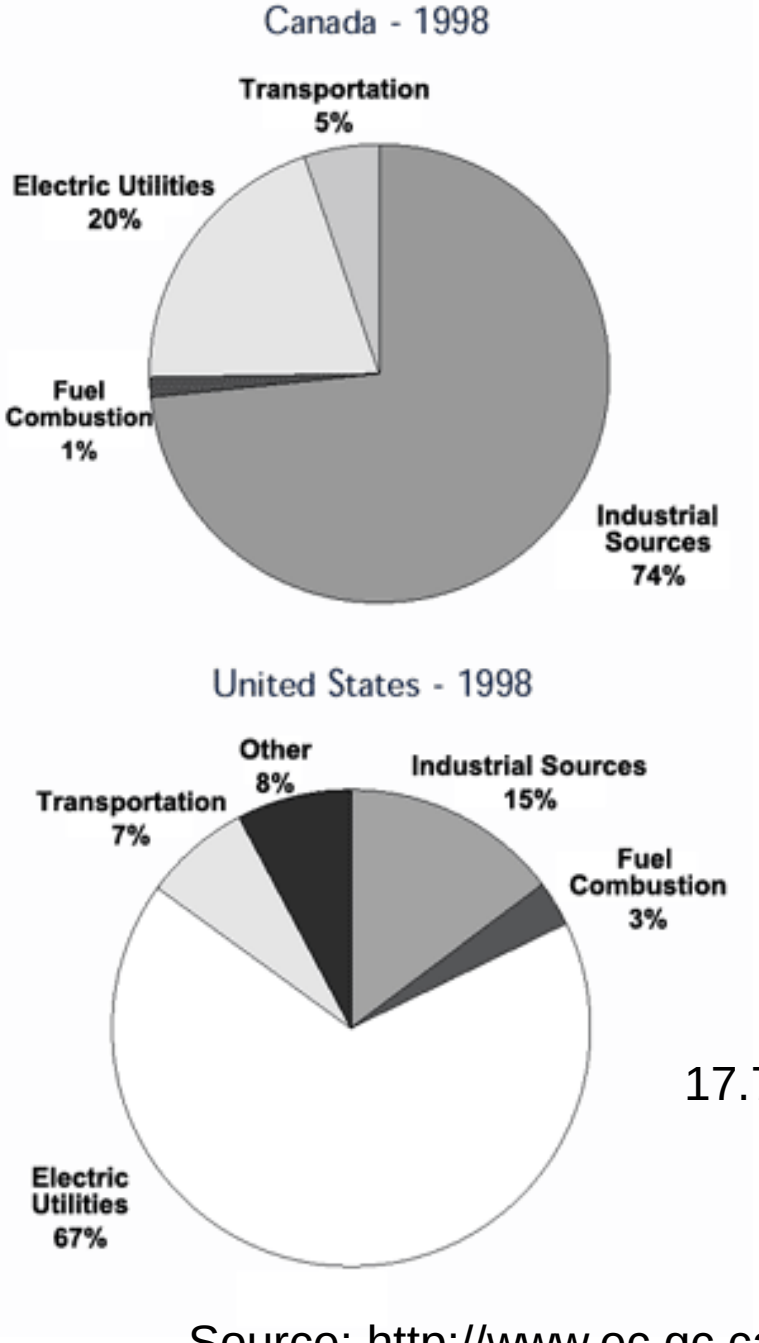




Source: Likens, Hubbard Brook

Policies for Reducing Acid Deposition

SO_2 Emissions from Canada and the United States in 1998

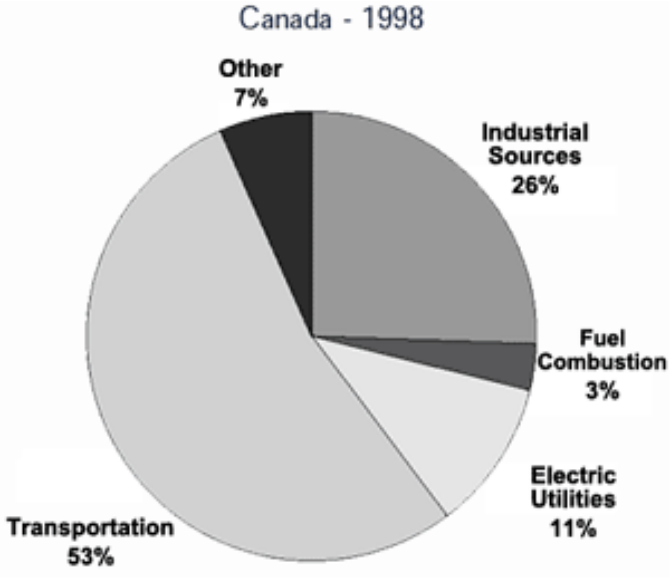


2.7 million tons

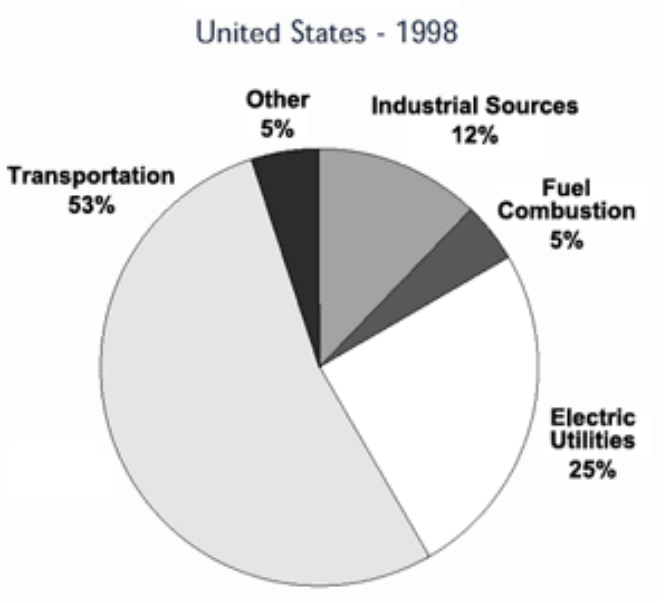
17.7 million tons

Source: http://www.ec.gc.ca/acidrain/acidfact.html

NOx Emissions from Canada and the United States in 1998



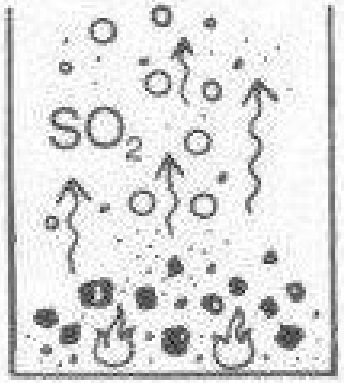
2.1 million tons



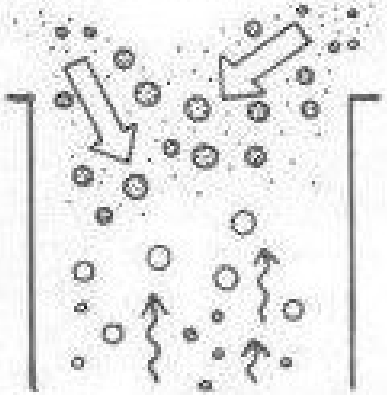
23.7 million tons

Source: http://www.ec.gc.ca/acidrain/acidfact.html

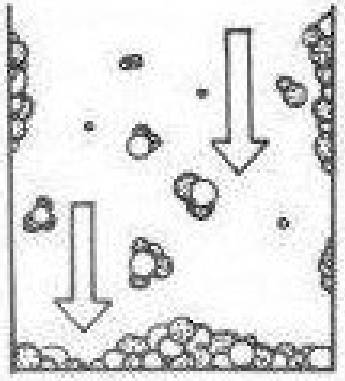
FLUE GAS DESULFURIZATION



Coal is burned and gives off sulfur dioxide gas.



A "flue" mix of lime or limestone and water is sprayed into the sulfur dioxide gas in the scrubbers.



Sulfur in the gas bonds with the flue mix and a solid forms for disposal.

Graphic by Stephen Greb

Scrubbing accounts for approximately 37% of the abatement in 2001 and virtually all of this abatement (1,993,000 tons) comes from new scrubbers installed on 30 Phase I units as a result of Title IV. These thirty units, located primarily in the Midwest and constituting 3% of the generating capacity and 4% of the 2001 heat input at Title IV units, accounted for 32% of total abatement. The remaining reductions attributed to scrubbing are reductions in excess of the percentage reduction required of scrubbers under non-Title IV regulation, which is typically 70% to 90%. Switching to lower sulfur fuels occurred almost exclusively (99.9%) at coal-fired units and it consisted entirely of switching to lower sulfur coals.

Source: Ellerman, D, 2003